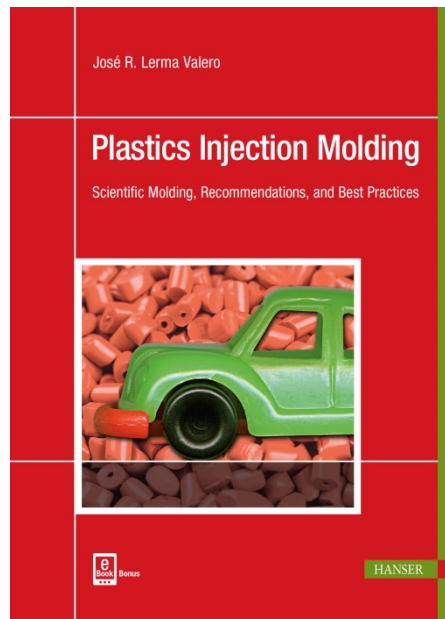


# HANSER



## Sample Pages

# Plastics Injection Molding

José R. Lerma Valero

ISBN (Book): 978-1-56990-689-7

ISBN (E-Book): 978-1-56990-690-3

**For further information and order see**

[www.hanserpublications.com](http://www.hanserpublications.com) (in the Americas)

[www.hanser-fachbuch.de](http://www.hanser-fachbuch.de) (outside the Americas)

© Carl Hanser Verlag, München

# Preface

This manual has been created thinking of plastics injection molding technicians as well as processing engineers and quality and design engineers.

The book was initially born as a small procedure guide for the company where I was working, for fine-tuning injection machines with the aim of creating a logical, safe, and optimized start-up method. Gradually, it grew and accumulated interesting information for the technicians, in my opinion, and it took shape until the final editing.

It was created for those who have ever needed a book to help and support them to understand the technology, materials, and thermoplastics injection process.

It is a book that helps identify the key points of the process and show, explore, and teach new tools to define more stable, robust, and consistent processes; a book with information, for example, such as the following:

- Clear explanations about the main key points of the thermoplastics injection molding process
- Glossaries with detailed explanations and easy-to-handle data tables
- Explanations about thermoplastics and their properties and behavior
- Support information to select material according to its further application
- Support information to determine the most suitable machine to use
- Real case examples, problems, analysis, and solutions
- Scientific injection molding explanations of tools, calculations, and portability
- Examples of defects and failures, their causes and possible solutions
- Easy and clear explanations for injection process optimization
- General processing recommendations

I hope that this book can be a tool for consulting and support during the professional life of the reader.

I also aim to encourage technicians toward a cultural change in both the analysis of problems and the parameterization and definition of robust plastics injection molding processes, where the transition from the empirical method toward the scientific method can be made using appropriate methodologies.

*José R. Lerma Valero*

September 2019

# About the Author

José R. Lerma Valero was born in Barcelona, Catalonia, in 1962; he is married and has a son. He obtained a superior degree in mechanics, with specialty in molds, and studied business management. He started his professional life as a trainee in a small injection molding factory.

José R. Lerma has dedicated close to 40 years of his professional life to the world of thermoplastics. Most of this professional life in plastics injection factories has been dedicated to producing parts for the automotive sector, producing both technical and aesthetic parts, painted, with chrome plating, etc. The functions and responsibilities he carried out in these injection plants have been of all kinds; for example, Processing Engineer, Technical Department Manager, Maintenance Manager, Production Manager, and Plant Manager.

Currently, and for almost 12 years, he is the Technical Manager for Spain and Portugal in Biesterfeld Ibérica SLU, leader in polymer distribution in Europe, with a portfolio of materials from the world's leading manufacturers.

José R. Lerma has been collaborating for more than 15 years with different technical centers in Spain as a leader of different seminars all related to plastics and the transformation of plastics, having trained hundreds of technicians in this technology.

In 2013 he published the book “Advanced Manual of Thermoplastics Transformation” in the Spanish language, with great success among plastics injection technicians.

It should also be noted that for six years he has developed and taught a specific seminar about scientific injection molding methodology in Spain, Portugal, and some Latin-American countries quite successfully.

All this accumulated background of experience in real day-to-day cases in factories as well as the training received and the experience of providing training in seminars to technicians is reflected and shared in this book.



# Contents

<b>Acknowledgments</b> .....	<b>V</b>	
<b>Preface</b> .....	<b>VII</b>	
<b>About the Author</b> .....	<b>IX</b>	
<b>Part 1: Plastics</b>		
<b>Polymers</b> .....	<b>3</b>	<b>CHAPTER 1</b>
1.1 Plastics .....	3	
1.2 Molecular Bonds .....	4	
1.3 Functionality .....	6	
1.4 Polymerization .....	6	
1.4.1 Polycondensation .....	6	
1.4.2 Polyaddition .....	6	
1.5 Determination of the Molecular Weight of Polymers .....	7	
1.6 Thermoplastics .....	8	
1.6.1 Classification of Thermoplastics .....	8	
1.6.1.1 According to Their Molecular Structure: Morphology .....	8	
1.6.1.2 According to Their Molecular Chain Form ....	11	
1.6.1.3 According to the Position of Atoms in the Chain	12	
1.7 Properties and Characteristics of Plastics .....	13	
1.7.1 Thermal and Physical Behavior .....	13	
1.7.1.1 Rheology .....	13	
1.7.1.2 Elastic Deformation .....	13	
1.7.1.3 Viscosity .....	13	
1.7.1.4 Glass Transition Temperature ( $T_g$ ) .....	15	
1.7.1.5 Melting Temperature ( $T_m$ ) .....	16	
1.7.1.6 Thermoplastics Behavior .....	17	
1.7.1.7 Changes of State in Amorphous Materials ....	17	
1.7.1.8 Changes of State in Semi-crystalline Materials	18	
1.7.1.9 Behavior under Load .....	19	
1.8 A Brief History of Plastics .....	21	
1.8.1 1900–1930 .....	22	
1.8.2 1950s .....	23	
1.8.3 1960s .....	24	
<b>Thermodynamic Behavior of Plastics: PVT Graphs</b> .....	<b>25</b>	<b>CHAPTER 2</b>
2.1 Thermodynamics .....	25	
2.2 PVT Graphs .....	25	
2.2.1 PVT Graphs Related to Amorphous and Crystalline Materials .....	25	

	2.2.1.1	Dosage Stage, Plastification, Melting . . . . .	26
	2.2.1.2	Injection Stage, Filling the Mold or Cavities . . .	26
	2.2.1.3	Hold Pressure Stage . . . . .	27
	2.2.1.4	Cooling Stage . . . . .	27
	2.2.1.5	Influence of Injection Molding Parameters Reflected in PVT Graphs . . . . .	30
	2.2.1.6	Crystallization Stages . . . . .	33
<b>CHAPTER 3</b>	<b>Burn Test</b> . . . . .		<b>35</b>
	3.1	Identification of Various Types of Plastics . . . . .	35
	3.2	Recognition and Identification of Plastics by Burn Test . . . . .	36
<b>CHAPTER 4</b>	<b>Water and Plastics, a Difficult Friendship</b> . . . . .		<b>37</b>
	4.1	Exposure on Duty . . . . .	37
	4.2	Water and Polymer in Molten State . . . . .	38
	4.3	Water-Sensitive Plastics . . . . .	38
<b>CHAPTER 5</b>	<b>Acronyms for Some Plastics, Reinforced Plastics, and Rubbers</b> . . . . .		<b>41</b>
<b>CHAPTER 6</b>	<b>General Features of Some of the Most Used Thermoplastics</b>		<b>46</b>
	6.1	Polyolefins . . . . .	46
	6.1.1	Polyethylene (PE) . . . . .	46
	6.1.1.1	High Density Polyethylene (HDPE) . . . . .	46
	6.1.1.2	Low Density Polyethylene (LDPE) . . . . .	46
	6.1.1.3	Linear Low Density Polyethylene (LLDPE) . . . . .	47
	6.1.1.4	Comparison of Different Structures of Polyethylenes . . . . .	48
	6.1.2	Polypropylene (PP) . . . . .	49
	6.1.2.1	PP Homopolymer Properties . . . . .	49
	6.1.2.2	PP Copolymers . . . . .	49
	6.1.3	Ethylene Vinyl Acetate (EVA) . . . . .	50
	6.1.4	Ethylene Vinyl Alcohol (EVOH) . . . . .	50
	6.2	Polyoxymethylene (POM) . . . . .	50
	6.3	Polystyrenes (PS) . . . . .	51
	6.3.1	PS General Purpose . . . . .	51
	6.3.2	Medium or High Impact PS (HIPS) . . . . .	52
	6.4	Acrylonitrile Butadiene Styrene (ABS) . . . . .	52
	6.5	Blend ABS-PC . . . . .	53
	6.6	Styrene Acrylonitrile (SAN) . . . . .	53
	6.7	Acrylonitrile Styrene Acrylic Rubber (ASA) . . . . .	54
	6.8	Polyamides (PA) . . . . .	54
	6.9	Polyesters . . . . .	56
	6.9.1	Polybutylene Terephthalate (PBT) . . . . .	56
	6.9.2	Polyethylene Terephthalate (PET) . . . . .	56

6.10	Polyphenylene Oxide (PPO) .....	57
6.11	Polycarbonate (PC) .....	58
6.12	Polymethylmethacrylate (PMMA) .....	58
6.13	Liquid Crystal Polymer (LCP) .....	59
6.14	Elastomers .....	59
6.14.1	Thermoplastic Elastomer (TPE-V) .....	59
6.14.2	Elastomer Thermoplastic Vulcanized (ETPV) .....	60
6.14.3	Thermoplastic Copolymer Elastomer Ether Ester (TPC ET) .....	60
6.14.4	Polyurethane (TPU) .....	61
6.14.4.1	Composition .....	61
6.15	Styrene Butadiene Copolymer (SBC) .....	62
6.16	Ionomer .....	63
6.17	Polyphenylene Sulfide (PPS) .....	63
6.17.1	Properties .....	63
6.17.2	Features .....	64
6.18	Polysulfones .....	64
6.18.1	Polyphenyl Sulfone (PPSU) .....	64
6.18.2	Polyethersulfone (PESU) .....	64
6.18.3	Polysulfone (PSU) .....	65

## **Chemical Resistances** ..... **66**

7.1	Chemical Substances .....	66
7.1.1	Ethers .....	66
7.1.2	Alkalis .....	67
7.1.3	Esters .....	67
7.1.4	Ketones .....	68
7.1.5	Aliphatic Compounds .....	69
7.1.6	Halogenated Hydrocarbons .....	69
7.1.7	Halogenated Compounds .....	69
7.1.8	Amines .....	69
7.1.9	Other Chemicals that May Attack Plastics .....	70

## **Additives** ..... **74**

8.1	Stabilizers .....	74
8.2	Lubricants .....	75
8.3	Antioxidants .....	76
8.4	UV Protection .....	76
8.4.1	Absorbents .....	76
8.4.2	HALS .....	76
8.5	Plasticizers .....	76
8.6	Antistatic Compounds .....	77
8.7	Flame Retardants .....	77
8.7.1	Combustion Mechanism of a Plastic .....	78
8.7.1.1	Solid Phase .....	78

## **CHAPTER 7**

## **CHAPTER 8**

	8.7.1.2 Gaseous Phase .....	78
	8.7.2 Some Types of Flame Retardants .....	79
8.8	Halogen-Free Flame Retardants .....	79
	8.8.1 Halogens .....	79
	8.8.2 Usual Names for Halogen-Free Materials .....	80
	8.8.3 Contribution of Halogens in Plastics .....	80
	8.8.4 Need for Alternatives to Halogenated Materials .....	80
8.9	Foaming Agents .....	81
8.10	Hydrolysis Stabilizers .....	81
8.11	Slips and Antiblocking .....	81
	8.11.1 Slips .....	81
	8.11.2 Antiblocking .....	81
8.12	Nucleating Agents .....	81
8.13	Compatibility Agents .....	82
8.14	Impact Modifiers .....	82
8.15	Fillers and Reinforcements .....	82
8.16	Mineral Additives .....	83
8.17	Antifriction Lubricants .....	84
8.18	Dyes and Pigments .....	84
8.19	Masterbatch .....	85
8.20	Applications .....	87
	8.20.1 Action Mode .....	87
	8.20.2 Addition Mode .....	87
	8.20.3 Some Products .....	87
<b>CHAPTER 9</b>	<b>Tests on Plastics .....</b>	<b>88</b>
9.1	Mechanical Tests .....	88
	9.1.1 Tensile Test ISO 527 1-2 .....	88
	9.1.2 Flexural Test ISO 178 .....	89
	9.1.3 Wear Resistance Test TABER ASTM D1044 .....	90
	9.1.4 Hardness Tests .....	90
	9.1.4.1 Ball Pressure Hardness Test ISO 2039-1 .....	90
	9.1.4.2 Rockwell Hardness Test ISO 2039-2 .....	90
	9.1.4.3 Shore A and Shore D Hardness Test ISO 868 ..	91
	9.1.5 Impact Charpy Test ISO 179 IZOD, ISO 180 .....	92
	9.1.5.1 Izod Test ISO 180 .....	92
	9.1.5.2 Charpy Test ISO 179 .....	93
	9.1.6 Scratch ASTM D3363 .....	93
	9.1.7 Compression Set Test .....	94
9.2	Thermal Tests .....	94
	9.2.1 Definitions .....	94
	9.2.2 Vicat Test ISO 306 .....	95
	9.2.3 HDT ISO 75 .....	95
	9.2.4 Hot Ball Pressure Test .....	96
	9.2.5 Relative Temperature Index (RTI) Test .....	96

9.2.6	Coefficient of Linear Thermal Expansion (CLTE) Test . . . .	97
9.2.7	Flammability Test UL94 . . . . .	97
9.2.8	Limited Oxygen Index (LOI) Test ISO 4589 1.2 . . . . .	99
9.2.9	Incandescent Glow Wire IEC 60695-2-13 and 2-12 . . . . .	100
9.2.10	Glow Wire Ignition Test (GWIT) IEC 60695-2-13, 2-12 . . .	101
9.2.11	Glow Wire Flammability Test (GWFT) IEC 60695-2-12 . . .	101
9.2.12	Reaction to Fire: Classification . . . . .	101
9.3	Electric Tests . . . . .	102
9.3.1	Dielectric Strength ASTM D149 IEC 60243-1 . . . . .	102
9.3.2	Dissipation Factor ASTM D150 IEC 60250 . . . . .	102
9.3.3	Dielectric Constant ASTM D150 IEC 60250 . . . . .	102
9.3.4	Comparative Tracking Index (CTI) IEC 60112 . . . . .	102
9.3.5	Surface Resistivity (SR) ASTM D527 IEC 6009 3 . . . . .	103
9.3.6	Volume Resistivity (VR) ASTM D527 IEC 6009 3 . . . . .	104
9.4	Rheological Tests . . . . .	104
9.4.1	Melt Flow Rate (MFR), MFI ISO 1133 . . . . .	104
9.4.2	MVI and MVR . . . . .	105
9.5	Weathering . . . . .	105
9.5.1	XW Weather-Ometer . . . . .	106
9.5.1.1	Accelerated Weathering . . . . .	106
9.5.1.2	Tests in Natural Environments . . . . .	107
9.5.2	Radiation . . . . .	107
9.6	Stress in Transparent Materials . . . . .	108
9.6.1	Residual Stress Measurement in Transparent Materials .	108
9.6.2	Method . . . . .	108
9.7	Colors: <i>Lab</i> System . . . . .	109
9.8	Chemical Resistance and Stress Cracking . . . . .	110
9.8.1	Electrical Properties . . . . .	110
9.8.1.1	HWI: Hot Wire Ignition . . . . .	110
9.8.1.2	HAI: High Ampere Arc Ignition . . . . .	111
9.8.1.3	Time of Arc Resistance (TAR) ASTM D 495 . . . . .	111
9.8.1.4	HVAR: High Voltage Arc Resistance to Ignition . . . . .	111
9.8.1.5	HVTR: High Voltage Arc Tracking Rate . . . . .	111
9.8.1.6	CTI: Comparative Tracking Index . . . . .	112
9.8.1.7	RTI: Relative Temperature Index . . . . .	112

## **Properties of Plastics: Understanding Technical Data Sheets 113**

## **CHAPTER 10**

10.1	Density . . . . .	114
10.2	Bulk Density . . . . .	115
10.3	Flow Rates . . . . .	115
10.3.1	Melt Volume Index (MVI) . . . . .	115
10.3.2	Melt Flow Index (MFI) . . . . .	116
10.4	Tensile Stress, Mechanical Resistance . . . . .	117
10.5	Elastic Modulus and Tensile Modulus . . . . .	118
10.6	Impact Resistance . . . . .	119
10.7	Coefficient of Linear Thermal Expansion (CLTE) . . . . .	120





13.3.5	Screw .....	176
13.4	Hardening Treatments for Injection Unit .....	176
13.5	The Pressure Multiplier .....	176

## **Key Parameters for Setting the Injection Molding Process ... 178**      **CHAPTER 14**

14.1	Injection Speed .....	178
14.2	Ideal Filling Situation .....	179
14.2.1	Filling Speed Rate .....	182
14.2.1.1	Very High Speeds .....	182
14.2.1.2	Very Low Speeds .....	182
14.2.1.3	What Affects the Filling Speed? .....	182
14.3	Melt Temperature .....	184
14.4	Screw Peripheral Speed .....	185
14.5	Back Pressure .....	186
14.6	Injection Pressure .....	187
14.6.1	Holding Pressure Switching Systems .....	188
14.7	Holding Pressure .....	188
14.8	Holding Pressure Time .....	189
14.8.1	Cavity Pressure Drop .....	189
14.8.2	Injected Mass Weight Control .....	189
14.9	Mold Temperature .....	190
14.10	Dosage .....	192
14.11	Cushion .....	192

## **Correct and Optimized Methodology for the Process Start-up 193**      **CHAPTER 15**

15.1	Requirements: Information Required .....	193
15.1.1	Material .....	193
15.1.2	Part .....	193
15.1.3	Mold .....	193
15.1.4	Machine .....	193
15.2	Possible Previous Calculations .....	194
15.3	Injection Machines Tune-up .....	196
15.3.1	Motion Setting .....	197
15.3.2	Injection Machine Start-up .....	198
15.3.2.1	Injection Fine-Tuning .....	198
15.3.3	Operative Method .....	201
15.3.4	Progressive Mold Filling .....	202
15.3.4.1	Progressive Filling Pressure Graphs .....	203
15.3.4.2	Hold Pressure Stage .....	203
15.3.5	Key Parameters of Process Control .....	204
15.3.6	Start-up and Fine-Tuning of Injection Machines— Interpreting Graphs .....	205
15.3.6.1	Injection and Cavity Pressures .....	205
15.3.6.2	Effect of Parameters .....	205
15.3.6.3	Cavity Pressure .....	206

15.3.7	Effects of the Different Parameters .....	206
15.3.7.1	Mold Temperature .....	206
15.3.7.2	Melt Temperature .....	206
15.3.7.3	Part Temperature .....	207
15.3.7.4	Dosage Stroke .....	207
15.3.7.5	Back Pressure .....	207
15.3.7.6	Injection Speed .....	207
15.3.7.7	Holding Pressure .....	207
15.3.7.8	Material Viscosity .....	208
<b>CHAPTER 16</b>	<b>Generic Recommendations for Injection Molding Conditions</b> .....	<b>209</b>
<b>CHAPTER 17</b>	<b>Mold Design Guide Recommendations</b> .....	<b>218</b>
17.1	Metals Versus Steels for Molds .....	218
17.2	Runners .....	220
17.3	Types of Gates .....	224
17.3.1	Most Common Gates .....	224
17.4	Mold Cooling .....	226
17.5	Cooling System in Cores .....	226
17.6	Venting .....	227
17.6.1	Deep .....	227
17.6.2	Venting for Runners .....	228
17.6.3	Venting in Distribution Channels .....	229
17.6.4	Venting in Ejectors .....	229
17.7	Draft Angles .....	230
17.8	Shrinkage .....	230
<b>CHAPTER 18</b>	<b>Gates: Types and Recommendations</b> .....	<b>231</b>
18.1	Fan Edge .....	231
18.2	Submarine or Tunnel Gate .....	232
18.3	Pin Point Gate .....	232
18.4	Tab Gate .....	233
18.5	Sprue Gate or Direct Gate .....	234
18.6	Flash Gate .....	234
18.7	Outer Ring .....	235
18.8	Inner Ring .....	235
18.9	Overlarged Jump Gate .....	236
18.10	Pin Gate .....	236
18.11	Most Common Injection Points .....	237
18.12	Central Flow Distribution Channels .....	238
<b>CHAPTER 19</b>	<b>Plastic Parts Design: Recommendations</b> .....	<b>239</b>
19.1	Recommendations .....	239
19.1.1	Ribs and Reinforcements Designs .....	239

19.1.1.1	Relative Torsion Resistance vs Reference	240	
19.1.1.2	Deformation at Constant Load	241	
19.1.2	Tensile Stresses	241	
19.1.3	Thickness Design	242	
19.1.3.1	Changes in Thickness	243	
19.1.3.2	Homogeneous Thicknesses	243	
19.1.4	Sharp Corners and Radii	244	
19.1.5	Influence of the Notches in the Impact Resistance	245	
19.1.6	Slots and Undercuts	246	
19.1.7	Snap-Fit	247	
19.1.8	Rigidity	248	
19.1.9	Creep and Relaxation	248	
19.1.10	Tubular Frames, Screw Holes	249	
<b>Injection: Some Practical Tips</b>		<b>250</b>	<b>CHAPTER 20</b>
20.1	Inspection of Runners and Gates Systems	250	
20.1.1	Gate Depth, Width, and Length	250	
20.1.1.1	Defects Due to the Gates	251	
20.1.2	Gates and Runners Design	252	
20.1.3	Spiral Effect or Flow Distribution	253	
20.1.4	Nozzles in Processes with Hot Runners	254	
20.1.5	Cooling	254	
20.1.6	Purging or Cleaning of the Injection Unit	255	
20.1.7	Venting	255	
20.1.8	POM Foaming Test	257	
20.1.9	Surface Tension	258	
20.1.9.1	Contact Angle	259	
20.1.9.2	Industrial Methods for Activating the Surface or Increasing Surface Tension	260	
<b>Part 4: Scientific Molding</b>			
<b>Scientific Molding or Injection by Advanced Methods</b>		<b>263</b>	<b>CHAPTER 21</b>
21.1	Knowledge and Training are Tools for the Future	263	
21.2	The Process	263	
21.3	Some Concepts Related to Scientific Molding	264	
21.3.1	Molding Processor	264	
21.3.2	Science	264	
21.3.3	Intelligence	264	
21.4	Machine Inputs vs Process Outputs	265	
21.5	New Processing Tools	267	
21.6	Advanced Methods—Scientific Injection Molding Tools	269	
21.6.1	Relative Viscosity Analysis or In-Mold Rheology Test	269	
21.6.2	Delta P: Determination Method	274	
21.6.3	Process Window: Determination Method (for Holding Injection Pressure Phase)	276	
21.6.4	Gate Seal Study	278	

	21.6.5	Method and Analysis of Injection Pressure Losses along the Filling System . . . . .	280
	21.6.6	Machine Portability . . . . .	282
	21.6.7	Cavities Balance Study . . . . .	283
	21.6.8	Study of Shear Stress at the Gates . . . . .	284
	21.6.9	Blank Templates . . . . .	287
	21.6.9.1	Gate Seal Study, Blank Template . . . . .	287
	21.6.9.2	In-Mold Rheology, Blank Template . . . . .	288
<b>CHAPTER 22</b>		<b>Using Spreadsheets: Advanced Molding and Machine Portability . . . . .</b>	<b>289</b>
	22.1	Thermoplastic Processing by Injection—Advanced Manual . . . . .	289
		<b>Part 5: Failure Analysis</b>	
<b>CHAPTER 23</b>		<b>Process Under Control, Failure Analysis . . . . .</b>	<b>303</b>
	23.1	Points to Consider . . . . .	303
	23.1.1	Clamping Unit . . . . .	303
	23.1.2	Barrels . . . . .	303
	23.1.3	Screws . . . . .	303
	23.1.4	Nozzles . . . . .	304
	23.1.5	Refrigeration System, Temperature Control in the Mold and the Machine . . . . .	304
	23.1.6	Water Connection System in Molds . . . . .	304
	23.1.7	Dryers and Dehumidifiers . . . . .	305
	23.1.8	Grinders . . . . .	306
	23.1.9	Hot Runner . . . . .	307
	23.1.10	Thermoregulators . . . . .	307
	23.1.11	Appearance Criteria . . . . .	307
	23.1.12	Resin Handling . . . . .	307
	23.2	Failure Analysis, Checks, and Optimizations . . . . .	309
	23.2.1	Preliminary Investigation of Failures . . . . .	309
	23.2.2	Process Optimization . . . . .	310
	23.2.2.1	Radii . . . . .	310
	23.2.2.2	Cold Slug . . . . .	310
	23.2.2.3	Steps for Analysis of Problems Derived from Plastics Injection Molding Process . . . . .	311
	23.2.3	Trials Injection Molding Parameters Template . . . . .	314
<b>CHAPTER 24</b>		<b>Typical Problems in Plastics Injection . . . . .</b>	<b>315</b>
	24.1	Lack of Drying or Dehumidification . . . . .	315
	24.1.1	Materials Drying . . . . .	316
	24.1.2	How to Properly Dehumidify . . . . .	317
	24.2	Filling System . . . . .	317
	24.2.1	Effects on the Quality of the Parts . . . . .	318
	24.2.2	Runners System Design . . . . .	319
	24.3	Proper Position of the Gate . . . . .	319
	24.3.1	Consequences of a Non-correct Gate Location . . . . .	320

24.3.2	Recommendations for Correct Gate Location	320
24.4	Hold Pressure Time Too Short	321
24.4.1	Hold Pressure Stage	321
24.4.2	Hold Pressure Time Too Short	321
24.5	Inadequate Melt Temperature	322
24.5.1	Incorrect Melt Temperature	322
24.5.2	Signs of Incorrect Melt Temperature	322
24.5.3	Correct Melt Temperature	322
24.5.3.1	Melt Temperature Measurement	322
24.5.3.2	30/30 Melt Temperature Measuring Method	323
24.6	Correct Mold Temperature	323
24.6.1	Incorrect Mold Temperature	324
24.6.2	Recommendations to Properly Adjust the Mold Temperature	324
24.7	Residues on Mold Surface	325
24.7.1	Types of Deposits	325
24.7.2	Mold Care	326
24.8	Excessive Material Drying	327

## **Defects in Injection Molded Parts** ..... **328**      **CHAPTER 25**

25.1	Defects in Parts Manufactured by Thermoplastics Injection Molding	328
25.1.1	Sink Marks or Uncompensated Shrinkage	328
25.1.2	Streaks	330
25.1.2.1	Streaks Caused by Burns	330
25.1.2.2	Streaks Caused by Moisture	330
25.1.2.3	Streaks Caused by Trapped Air	331
25.1.3	Weld Lines	332
25.1.4	Grooves, Vibrations, and Corona Effects	333
25.1.5	Gloss	333
25.1.6	Jetting	334
25.1.7	Spots and Markings near the Gate	335
25.1.8	Black Spots	335
25.1.8.1	Process	335
25.1.8.2	Machine	336
25.1.8.3	Polymer	336
25.1.9	Inhomogeneous Material	336
25.1.10	Blushes near the Gate	337
25.1.11	Bubbles	337
25.1.12	Cracking	337
25.1.13	Delamination	337
25.1.14	Splay, Silver Marks	337
25.1.15	Warpage	338
25.1.16	Stress Cracking, ESC	338
25.1.17	Surface Scratching	338
25.2	Defects in Injection Molding and Painted Parts	338
25.2.1	Holes and Craters	338

25.2.2	Trapped Air	338
25.2.3	Part Molded with Stress	339
25.2.4	Cracks	339
25.2.5	Irregularities	340
25.2.5.1	Sinkings	340
25.2.5.2	Peaks/Crawling	340
25.2.5.3	Lack of Adhesion	341
25.3	Cross Cut Test	341
25.4	Defects in Chrome Plating on Plastic Parts	342
25.4.1	Defects	343
25.4.2	Peaks, Spots, Bubbles	343
25.4.3	Blisters	343
25.4.4	Adhesion	344
<b>CHAPTER 26</b>	<b>Analysis of Real Cases</b>	<b>345</b>
26.1	Broken Support Brackets	345
26.1.1	Drying of Material	345
26.1.2	Filling System Review and Optimization	347
26.2	Pulleys that Do Not Work	349
26.2.1	Radii	349
26.2.2	Material Selection	350
26.3	Broken Gears	350
26.4	Unfilled PC Cover	351
26.5	Dimensional Instability in Parts	352
26.6	Insufficient Filling	355
26.7	Several Problems with Polycarbonate	356
26.7.1	A Plastic Chair Full of Problems	356
26.7.1.1	Concentric Circular, Dark Area around the Gate	356
26.7.1.2	Weld Lines in the Back Chair Grill	356
26.7.1.3	Marks in the Cavity Gate	357
26.7.1.4	Streaks	357
26.8	Support Breaks	357
26.9	Deformation of ABS Part	359
26.10	Bimetallic Effect	360
26.11	Hesitation Effect (Flow Stoppage)	361
26.12	Gloss Caused by the Glass Fiber Reinforcement	363
26.13	Pressure-Limited Process: Always a Mistake to Avoid	365
26.14	Streaks in Transparent Polycarbonate	367
26.14.1	Dehumidifying	367
26.14.2	Back Pressure	368
26.14.3	Suction	368
26.14.4	Gate	368
26.15	Polyamide Parts Cannot Withstand the Assembly Stress	369
26.15.1	Gates	371

26.16	Unbalanced Runners .....	372
26.17	Material Degradation .....	372
26.18	TPU: The Unknown Thermoplastic .....	373
26.18.1	What is TPU? .....	374
26.18.1.1	Dehumidification .....	374
26.18.1.2	Back Pressure .....	375
26.18.1.3	Hold Pressure .....	375
26.18.1.4	Cooling and Total Time Cycle .....	376
26.19	Bubbles .....	376
26.19.1	Bubbles Caused by Trapped Air .....	377
26.19.2	Bubbles Caused by Vacuum .....	377
26.20	The Secret of the Night Shift Manager .....	378
26.20.1	Dryers and Dehumidifiers .....	379

**Part 6: Reference Material**

<b>Reference Data Tables</b> .....	<b>383</b>	<b>CHAPTER 27</b>
27.1	Maximum Residence Time .....	383
27.2	Usual Mold Temperatures .....	383
27.3	Shrinkage .....	384
27.4	Drying Conditions .....	384
27.5	Maximum Allowed Humidity Data .....	385
27.6	Recommended Depth Venting Channels .....	386
27.7	Mold and Melt Temperatures, Shear, and Other Properties .....	386
27.8	Maximum Peripheral Speeds .....	387
27.9	Density, Melt at Room Temperature .....	388
<b>Bibliography</b> .....	<b>389</b>	<b>CHAPTER 28</b>
<b>Glossary</b> .....	<b>390</b>	<b>CHAPTER 29</b>
<b>Disclaimer</b> .....	<b>394</b>	
<b>Index</b> .....	<b>395</b>	



## 7.1.9 Other Chemicals that May Attack Plastics

Oils



Fatty acids



Alcohols



Detergents



Acids

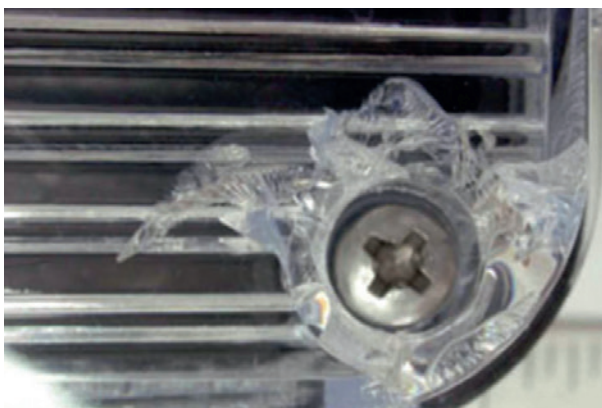


Environmental stress cracking (ESC) is a major cause of failures in plastics, especially amorphous plastics.

Exposure of polymers to chemicals tends to accelerate the process of cracking or crazing. This process begins with stress much lower than that needed to produce cracks simply in contact with air. The mere effect of both conditions separately, stress or contact with an aggressive chemical, need not necessarily result in ESC. This phenomenon usually occurs when a combined action of both effects occurs.

ESC depends on multiple factors such as crystallinity, surface roughness, residual stress, presence of chemical agents, temperature, and strain level or molecular stretching.

The ESC effect can be minimized by lower residual stress and molecular stretching during the injection process. The use of cold molds should be avoided, as they cause residual stresses that will accelerate the ESC. Polymers of higher molecular weight should be used, because they are more resistant to ESC.



**Chemical resistances**

- LIMITED RESISTANCE, MINOR OR MODERATE ATTACK. USE BRIEFLY
- GOOD RESISTANCE, MINOR ATTACK
- EXCELLENT RESISTANCE, WITHOUT ATTACK
- LOW RESISTANCE. NOT RECOMMENDED

	LDPE	HDPE	PP	PP C	PS	PC
DILUTED ACIDS						
CONCENTRATED ACIDS						
ALCOHOLS						
ALDEHYDES						
BASES						
ESTERS						
ALIPHATIC HYDROCARBONS						
AROMATIC HYDROCARBONS						
HALOGENATED HYDROCARBONS						
KETONES						
MINERAL OIL						
VEGETAL OIL						
MAX TEMPERATURE °C	80	120	135	121	70	130
MIN TEMPERATURE °C	-50	-100	0	-40	0	-135
AUTOClave STERILIZATION						
MICROWAVES						
GAS STERILIZATION						
DRY HEAT STERILIZATION						
GAMMA RAY STERILIZATION						
CHEMICAL STERILIZATION						
NITROGEN PERMEABILITY	20	3	4.4	4.2	3	
CO <sub>2</sub> PERMEABILITY	280	45	92	65	75	
OXYGEN PERMEABILITY	60	10	25	24	15	

Chemical resistances

	LDPE		HDPE		PP		PC		PS		SAN		ABS	
	20	50	20	50	20	50	20	50	20	50	20	50	20	50
TEMPERATURE														
ACETALDEHYDE	Blue	Red	Blue	Yellow	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
ACETIC ACID	Blue	Red	Blue	Yellow	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
ACETONE	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
AMMONIUM HYDROXIDE	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
AQUA REGIA	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
BENZENE	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
WATER BROMINE	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
BUTYL ACETATE	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
BUTYL ALCOHOL	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
CHLORINE WATER	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
CHLOROFORM	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
CYCLOHEXANE	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
ETHYL ACETATE	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
ETHYL ALCOHOL	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
ETHYL OXIDE	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
FORMALDEHYDE	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
FORMIC ACID	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
FUEL OIL	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
METHYL ALCOHOL	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
METHYLETHYL KETONE (MEK)	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
MINERAL OIL	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
SODIUM OXIDE 50 %	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
SODIUM CHLORIDE 20 %	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
SULFURIC ACID 10 %	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow
SULFURIC ACID 98 %	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
TOLUENE	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red
VEGETAL OIL	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow	Blue	Yellow

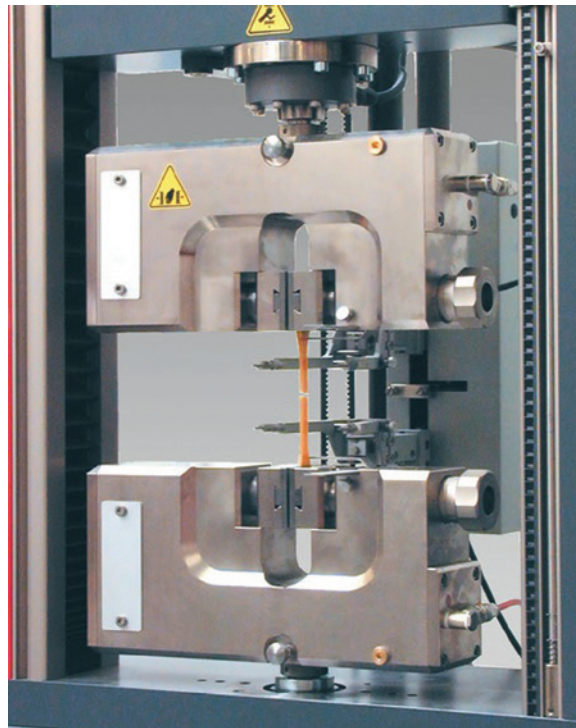
	EXCELLENT RESISTANCE, WITHOUT ATTACK		POOR RESISTANCE (ATTACKED OR DISSOLVED), NOT RECOMMENDED
	LIMITED RESISTANCE, MODERATE ATTACK		NO DATA
	GOOD RESISTANCE, MINOR ATTACK		

Chemical resistances

NOT RESISTANT NOT RECOMMENDED RESISTANT

	ABS	EVA	HDPE	LDPE	PA 6	ZYTEL PA 66	PA 12	PC	PMMA	DELRIN POM	PP	XTEL RYTON	PS	SAN
WEAK ACIDS	Green	Green	Green	Green	Green	Green	Green	Green	Orange	Orange	Green	Orange	Green	Green
STRONG ACIDS	Orange	Orange	Green	Orange	Red	Red	Red	Orange	Red	Red	Orange	Red	Orange	Green
OXIDANT ACIDS	Red	Red	Orange	Red	Red	Red	Red	Orange	Red	Red	Red	Red	Red	Red
WEAK ALKALIS	Green	Green	Green	Green	Green	Green	Green	Red	Green	Green	Green	Green	Green	Green
STRONG ALKALIS	Green	Green	Green	Green	Orange	Orange	Orange	Red	Orange	Green	Green	Green	Green	Green
SALTS (SOLUTIONS)	Green	Green	Green	Green	Green	Green	Green	Orange	Green	Green	Green	Green	Green	Green
HALOGENS	Red	Red	Orange	Red	Red	Red	Red	Green	Orange	Red	Orange	Red	Red	Red
ALIPHATIC HYDROCARBONS	Green	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red	Orange
CHLORINATED HYDROCARBONS	Red	Red	Red	Red	Orange	Orange	Orange	Red	Red	Green	Green	Green	Red	Red
ALCOHOLS	Green	Green	Green	Orange	Orange	Orange	Orange	Orange	Red	Green	Green	Green	Red	Red
ESTERS	Red	Red	Green	Orange	Green	Green	Green	Orange	Red	Red	Orange	Orange	Red	Red
KETONES	Red	Red	Green	Orange	Green	Green	Green	Orange	Red	Orange	Orange	Green	Red	Red
ETHERS	Red	Red	Red	Green	Green	Green	Green	Red	Orange	Green	Red	Orange	Red	Red
ALDEHYDES	Red	Green	Red	Orange	Orange	Orange	Orange	Red	Orange	Orange	Green	Orange	Red	Red
AMINES	Green	Orange	Green	Green	Green	Green	Green	Green	Green	Orange	Orange	Orange	Green	Green
ORGANIC ACIDS	Green	Orange	Green	Green	Orange	Orange	Orange	Orange	Red	Green	Orange	Orange	Green	Green
AROMATIC HYDROCARBONS	Red	Red	Red	Red	Green	Green	Green	Red	Orange	Orange	Orange	Green	Red	Red
OIL AND DERIVATIVES	Green	Red	Red	Red	Green	Green	Orange	Orange	Red	Green	Orange	Green	Red	Orange
MINERAL OILS	Green	Red	Green	Orange	Green	Green	Green	Green	Green	Green	Green	Green	Orange	Green
FATS AND OILS	Green	Orange	Green	Orange	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
UNSATURATED CHLORINATED HYDROCARBONS	Red	Red	Orange	Red	Orange	Orange	Orange	Red	Red	Green	Orange	Orange	Red	Red

### 9.1.2 Flexural Test ISO 178

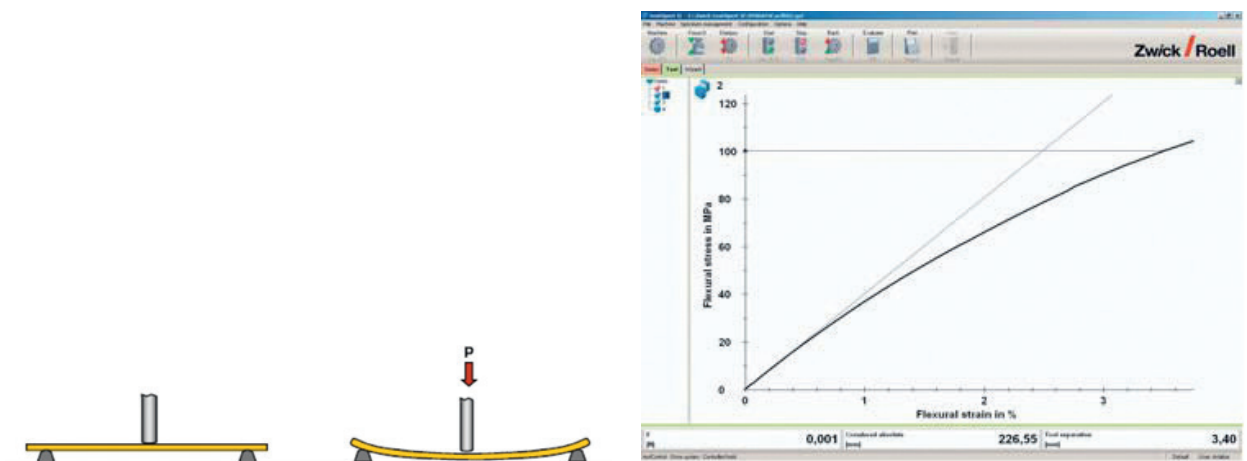


**Figure 9.1** Universal testing machine; source: Zwick-Roell

This flexural test measures the extent of bending resistance of a material and its stiffness. To carry it out, a specimen is placed so that it rests on two points. Then, pressure is applied at its midpoint.

**Test speed:** 2 mm per minute.

To calculate the flexural modulus, the load/deflection curve is drawn. The flexural modulus is determined by the slope of the line tangent to the stress-strain curve in the region where the plastic has not yet been permanently deformed or where elastic strain occurs.



**Figure 9.2** Graph of flexural stress; source: Zwick-Roell

### 9.1.3 Wear Resistance Test TABER ASTM D1044



**Figure 9.3** TABER machine;  
source: Neurtek

This wear resistance test measures the amount of material loss by abrasion or wear.

The sample is mounted on a turntable which rotates at 60 rpm. Loads are applied as weights that push the abrasive wheels against the sample. After a certain number of cycles the test is stopped.

The mass lost by abrasion is indicated in mg/1000 cycles.

### 9.1.4 Hardness Tests

#### 9.1.4.1 Ball Pressure Hardness Test ISO 2039-1

A 5 mm diameter ball of hardened and polished steel is pressed at 358 N on a sample surface with a minimum thickness of 4 mm. 30 seconds after, the depth of impression is measured.

Hardness pressure is calculated by dividing the load applied by the mark area ( $\text{N}/\text{mm}^2$ ).

#### 9.1.4.2 Rockwell Hardness Test ISO 2039-2

The diameter of the ball depends on the Rockwell scale used. The indenter is made of hardened and ground steel. The sample is subjected to a lighter load. A heavier load is then applied and, finally, the lighter load is applied again.

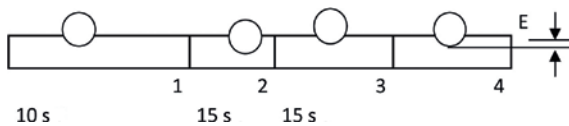
The measurement is based on the total penetration depth achieved. The values are always between 50 and 115 (in Rockwell units).

The scale increases in severity R to M through L.



**Table 9.1** Rockwell Hardness Test

Rockwell hardness scale	Lower load (N)	Higher load (N)	Ball diameter (mm)
R	98.07	588.4	12.7
L	98.07	588.4	6.35
M	90	980.7	6.35

**Figure 9.4** Rockwell hardness conditions and sequence**Figure 9.5** Rockwell hardness test machine; source: Zwick-Roell

Rockwell hardness calculation =  $130 - E$  (see Figure 9.4).

Units: 0.002 mm (one unit per each 0.002 mm of the mark depth).

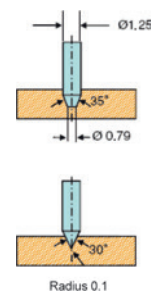
### 9.1.4.3 Shore A and Shore D Hardness Test ISO 868

The Shore A test is intended for soft materials. The Shore D test is intended for harder materials.

Pressure is applied on the sample for 15 seconds. Hardness is read on the durometer scale. Values range from 0 (total penetration: 2.5 mm) to 100 (no penetration).

Shore A hardness ranges from 10 to 90. Shore D hardness ranges from 20 to 90.

Shore A values over 90 require switching to the Shore D scale. Shore D values under 20 require switching to the Shore A scale.





**Figure 9.6** Shore A durometer;  
source: Zwick-Roell

### 9.1.5 Impact Charpy Test ISO 179 IZOD, ISO 180

The sample specimens are different between ISO and ASTM. See Table 9.2.

**Table 9.2** Sample Dimensions for Charpy Impact Test

	Thickness	Length
ISO sample	4 mm	80 mm
ASTM sample	3 mm	60 mm

The impact Charpy test is used to estimate the degree of weakness or strength of material samples subjected to impact. We can thus compare the toughness of different materials.

The sample is placed in the specimen holder. Then, a pendulum hammer (with a hardened steel tip of a certain radius) is dropped from a certain height. The impact causes shearing of the sample material due to the sudden load.

The height difference between the baseline and the residual height reached by the hammer represents the energy absorbed by the sample.

This test can be performed at different temperatures. It can also be performed with or without notches in the sample.

#### 9.1.5.1 Izod Test ISO 180

The result of this test is obtained by dividing the energy required to break the sample by the initial area. The result is expressed in kilojoules per square meter,  $\text{kJ/m}^2$ .

# The Injection Molding Machine



**Figure 13.1** Injection molding machine; source: Wittmann-Battenfeld

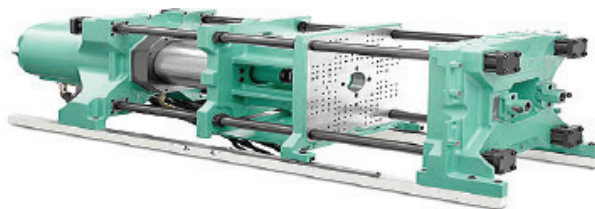
The characteristics and instructions included in catalogs and technical documentation brochures provided by injection machine manufacturers allow us to determine if a machine can be technically optimal for producing a particular project or part made by an injection molding process.

The injection machine can be divided into two main units: the clamping unit and the injection unit.

The clamping unit comprises, among others, the clamping force, the moving plate stroke, the tie bar free spacing, the mold minimum and maximum thicknesses, clamping and opening mold speed, etc.

The injection unit incorporates several characteristics, like the screw diameter, maximal pressure,  $L/D$  ratio, compression ratio, plasticizing capacity, maximal injection volume, heating power, maximal injection speed, etc.

## 13.1 Clamping Unit



**Figure 13.2** Clamping unit

**Clamping unit determines:**

Clamping force	Mold maximum and minimum thicknesses
Moving plate stroke	Plate thickness
Tie bar free spacing	Ejection stroke



### 13.1.1 Clamping Force

#### Function and characteristics

- Keeping the mold closed so it does not open due to the injection pressure thrust during the cavity filling and packing.
- When the product obtained by multiplying the projected part area in the mold by the injection pressure needed exceeds the closing force, the tie bars are overstressed and elongate even more. They can exceed the steel elastic tensile limit and break or deflect the clamping plates.
- The mechanical clamping systems are stiffer than hydraulic clamping systems.
- The hydraulic clamping system exerts pressure close to the center of the plate.
- The latest generation of mechanic toggle clamping systems also concentrate strength close to the center of the movable plate.

#### Movable platen stroke

A longer stroke will make the machine more versatile. In the hydraulic clamping systems, the total stroke of the piston is equal to the sum of the mold thickness and the maximum opening mold stroke.

#### Tie bars distance

The distance should be the widest possible, provided that the plate bending will be respected.

#### Stationary and movable platen

They should be parallel. The weight of the movable platen and mold must rest on the base of the bed and not on the tie bars.

#### Mold size regarding the platen size

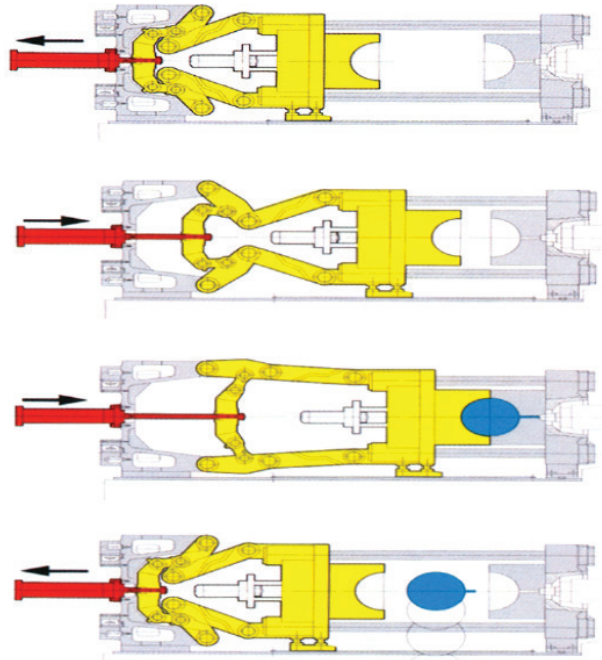
According to the rule of thumb, the molds whose base area regarding the movable platen is less than  $\frac{1}{4}$  of the area of the platen should not be placed.

The projected area of the molds used should not be **less than a quarter of the area delimited by the tie bars in the clamping platen**. If the mold area were smaller, the plates could be flexed more than recommended.

### 13.1.2 Clamping Unit Systems

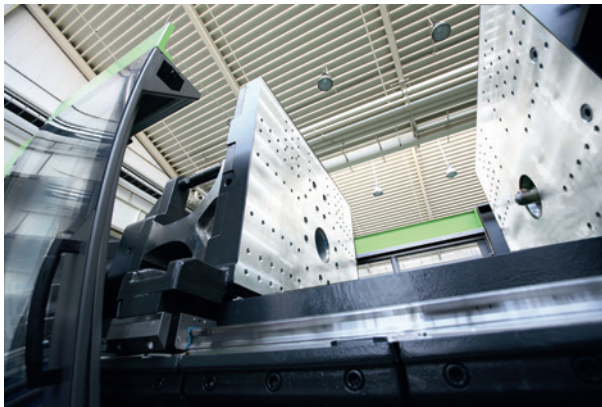
According to their design, we can distinguish the following sealing systems:

- Mechanic toggle clamping system
- Hydraulic clamping system
- Hydraulic two-stage piston system
- Tie-barless system
- Electrical system



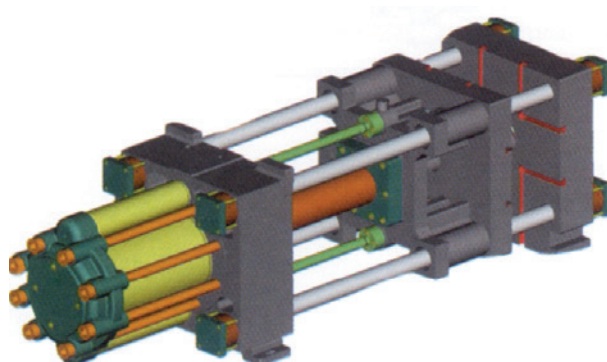
**Figure 13.3** Toggle clamping system schema; source: Ascamm

### 13.1.2.1 Mechanical Toggle Clamping System



**Figure 13.4** Tie-barless clamping unit detail; source: Helmut Roegele

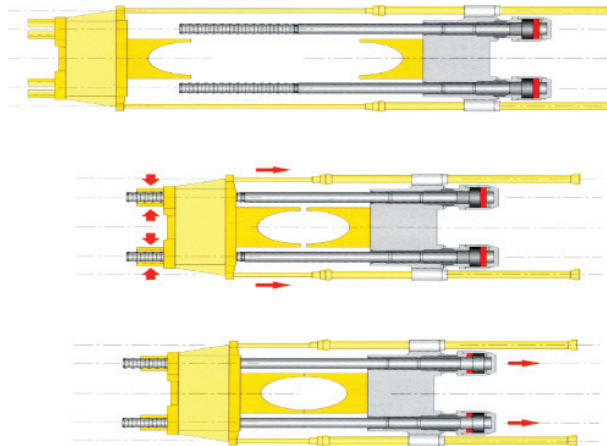
### 13.1.2.2 Hydraulic Piston Clamping System



**Figure 13.5** Hydraulic clamping system; source: Ascamm

There are several kinds of two-stage clamping systems that may be included within the hydraulic clamping systems. The most common system is a mechanical lock in the machine made by two very small hydraulic cylinders, driving two locking parts which act over the central axis. Once the central axis is locked, the high pressure enters through a larger cylinder (pressure cylinder), moving it only a few millimeters, to provide the necessary and programmed clamping force.

### 13.1.2.3 Hydraulic Closure System for Large Tonnages

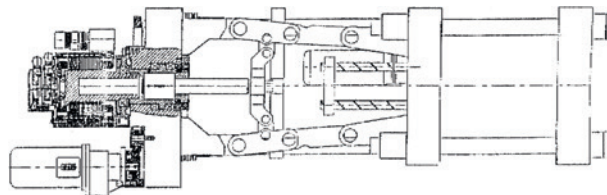


**Figure 13.6** Hydraulic clamping system scheme; source: Ascamm

There are as many hydraulic clamping systems as there are machine manufacturers. All of them have tried to develop more versatile, fast, accurate, and low-maintenance systems.

In general, these devices have a system of small-section and low-volume piston to effect a fast closing movement. Thus, this movement requires little volume of oil and, therefore, has a low energy cost and is performed very rapidly. The system is complemented with a large piston. This piston performs the final locking of clamping force by a short stroke.

### 13.1.2.4 Servoelectric Clamping: Movements Made by Servomotors, Bearings, and High-Precision Screws



**Figure 13.7** Servoelectric motor clamping

# Generic Recommendations for Injection Molding Conditions

**Attention:** follow carefully the recommendations in this chapter. The author assumes no responsibility for incidents, accidents, damage to equipment or people, or adverse outcomes that may occur.

MATERIAL	NAME	MOLD TEMP	MELT TEMP	MELT TEMP	MELT TEMP	MAX MELT TEMP	RESIDENCE TIME
FEP	FLUORINATED ETHYLENE POLYPROPYLENE	200-240°C	345-370°C	330-350°C	335-350°C	390°C	5 min

DRYING	
TEMPERATURE	TIME
150°C	2-4 hours

VENTING DEEP	
GATES	SHRINKAGE

PERIPH SPEED m/s	0.5
BACK PRESSURE bar	< 60
INJECTION PRESSURE bar	1050
HOLD PRESSURE bar	600

COMMENTS
FILTERS, CAPS, AND GASKETS

MATERIAL	NAME	MOLD TEMP	MELT TEMP	MELT TEMP	MELT TEMP	MAX MELT TEMP	RESIDENCE TIME
PEI	POLYETHERIMIDE	175°C	325-410°C	320-400°C	310-375°C	415°C	5 min

DRYING	
TEMPERATURE	TIME
150°C	4 hours

VENTING DEEP	
GATES	SHRINKAGE

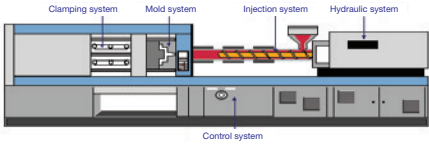
PERIPH SPEED m/s	0.5
BACK PRESSURE bar	< 5
INJECTION PRESSURE bar	2000
HOLD PRESSURE bar	1800

COMMENTS
ELECTRICAL COMPONENTS INTEGRATED CIRCUITS' HOLDERS f/e 150:1

MATERIAL	NAME	MOLD TEMP	MELT TEMP	MELT TEMP	MELT TEMP	MAX MELT TEMP	RESIDENCE TIME
PEEK	POLYETHER ETHER KETONE	150-160 °C	370-380 °C	350-370 °C	340-350 °C		

DRYING	
TEMPERATURE	TIME
150°C	4 hours



PERIPH SPEED m/s	
BACK PRESSURE bar	< 5
INJECTION PRESSURE bar	1500
HOLD PRESSURE bar	1000

VENTING DEEP	
--------------	--

GATES	SHRINKAGE

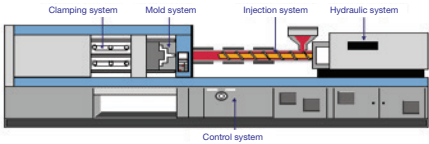
**COMMENTS**

CLUTCH PLATES  
GEARS  
RT1 260  
TF 343  
f/e 200:1

MATERIAL	NAME	MOLD TEMP	MELT TEMP	MELT TEMP	MELT TEMP	MAX MELT TEMP	RESIDENCE TIME
PSU/PPSU/PEU	POLYSULFONES	150°C	315-380°C	310-370°C	295-365°C	380°C	30 min

DRYING	
TEMPERATURE	TIME
150°C	3 hours



PERIPH SPEED m/s	0.6
BACK PRESSURE bar	< 1
INJECTION PRESSURE bar	2000
HOLD PRESSURE bar	1200

VENTING DEEP	
--------------	--

GATES	SHRINKAGE

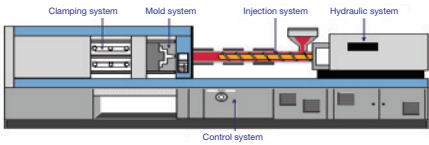
**COMMENTS**

MEDICAL PRODUCTS  
AIRCRAFT INDOORS  
f/e 60-120:1

MATERIAL	NAME	MOLD TEMP	MELT TEMP	MELT TEMP	MELT TEMP	MAX MELT TEMP	RESIDENCE TIME
PC	POLYCARBONATE	80-120°C	295-315°C	285-315°C	275-300°C	320°C	7 min

DRYING	
TEMPERATURE	TIME
120°C	4 hours



PERIPH SPEED m/s	0.5
BACK PRESSURE bar	< 10
INJECTION PRESSURE bar	2000
HOLD PRESSURE bar	1200

VENTING DEEP	0.05mm
--------------	--------

GATES	SHRINKAGE
60-70 % thickness	0.6-0.8%

**COMMENTS**

<p><b>STRENGTHS</b></p> <p>HIGH TRANSMITTANCE IMPACT RESISTANCE UNTIL -150°C DIMENSIONAL STABILITY</p>	<p><b>WEAKNESSES</b></p> <p>UV RESISTANCE HOT WATER, HYDROLYSIS LOW RESISTANCE TO OILS AND FATS</p>
--	---

f/e 30-70:1

MATERIAL	NAME	MOLD TEMP	MELT TEMP	MELT TEMP	MELT TEMP	MAX MELT TEMP	RESIDENCE TIME
PBT	POLYBUTYLENE TEREPHTHALATE	80-100 °C	235-250 °C	225-240 °C	215-230 °C	270°C	2 min

DRYING	
TEMPERATURE	TIME
120°C	2-5 hours

VENTING
DEEP

GATES	SHRINKAGE
	1.4-2%

PERIPH SPEED m/s	0.35
BACK PRESSURE bar	< 7
INJECTION PRESSURE bar	1300
HOLD PRESSURE bar	750

COMMENTS	
<b>STRENGTHS</b> DIMENSIONAL STABILITY OUTDOORS CHEMICAL RESISTANCE TO OILS	<b>WEAKNESSES</b> IMPACT RESISTANCE STRICT DRYING, HYDROLYSIS LOW RESISTANCE TO GASOLINES AND KETONES

f/e 160-200:1

MATERIAL	NAME	MOLD TEMP	MELT TEMP	MELT TEMP	MELT TEMP	MAX MELT TEMP	RESIDENCE TIME
PET	POLYETHYLENE TEREPHTHALATE	130-140 °C	270-285 °C	270-285 °C	270-280 °C	290°C	4 min

DRYING	
TEMPERATURE	TIME
130°C	5 hours

VENTING
DEEP

GATES	SHRINKAGE
	1.2-2%

PERIPH SPEED m/s	0.3
BACK PRESSURE bar	< 10
INJECTION PRESSURE bar	1600
HOLD PRESSURE bar	1000

COMMENTS	
<b>STRENGTHS</b> UV RESISTANCE ACIDS RESISTANCE STIFFNESS	<b>WEAKNESSES</b> STRICT DRYING PERMEABILITY TO CO <sub>2</sub>

f/e 350:1

MATERIAL	NAME	MOLD TEMP	MELT TEMP	MELT TEMP	MELT TEMP	MAX MELT TEMP	RESIDENCE TIME
PPO	POLYBUTYLENE OXY MODIFIED	60-110 °C	250-290 °C	220-270 °C	219-250 °C	290 °C	

DRYING	
TEMPERATURE	TIME
100°C	2 hours

VENTING
DEEP

GATES	SHRINKAGE
	0.5-0.7%

PERIPH SPEED m/s	0.4
BACK PRESSURE bar	< 10
INJECTION PRESSURE bar	1800
HOLD PRESSURE bar	1400

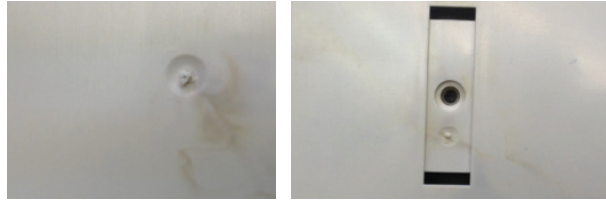
  

COMMENTS	
<b>STRENGTHS</b> DIMENSIONAL STABILITY IMPACT RESISTANCE	<b>WEAKNESSES</b> IMPACT RESISTANCE RESISTANCE TO GASOLINES AND KETONES

f/e 100-200:1

## 25.1.2 Streaks

### 25.1.2.1 Streaks Caused by Burns



This thermal degradation is caused by excessive temperatures and/or residence times; gases are generated by the decomposition of the polymer or additive pack. Brown or silver streaks can be seen in the workpiece surface.

When the molecular structure is thermally degraded, the molecular chain can decrease, and silver streaks appear. The change in the macromolecules causes a brownish discoloration.

The heat required for thermal degradation of the material may come from the injection unit setting, from an excessive shear during dosing (back pressure) by a high peripheral speed (rpm), from an excessive shear on sharp edges, from sudden changes of direction, etc.

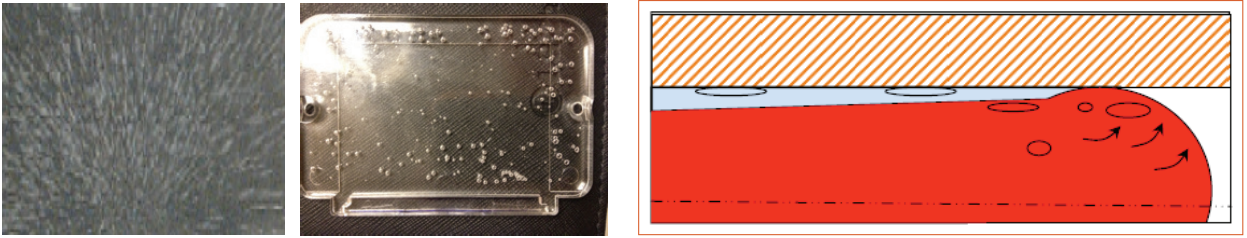
#### Verifications—To Check:

- Check if the melt temperature is near the upper limit recommended or even above.
- See if the streak appears behind narrow sections of passage of material.
- Check if the defect can be reduced by decreasing the injection speed.
- Check if the reduction in the melt temperature has a positive effect on the defect.
- Check if the degradation streak is affected by a high residence time caused by interruptions, excessive cycle, or inadequate machine size.
- Check for a considerable amount of regrind material or dust from the regrind process.
- Check there are no retentions inside the hot runners.
- Check that the nozzle is working properly and there are no retentions. Pay attention to shut-off hydraulic nozzles.
- Check that time and temperature of pre-drying material are not excessively high.
- Check that the shear originated during the dosing by screw rotation is not excessive (keep within the recommended limits for the material).

### 25.1.2.2 Streaks Caused by Moisture

They appear on the part surface with the shape of comet trails. The surface surrounding the silver streaks is porous and rough. This can be seen under a microscope.





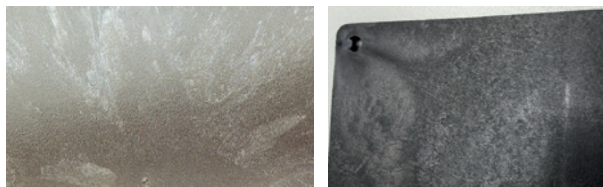
**Figure 25.4** Melt flow and gas bubbles during the cavity filling; source: Ascamm

Residual humidity in the melt causes gas evaporation of water inside. These gas bubbles tend to come out to the surface by the advancing flow effect from inside to outside. Trapped bubbles burst at the surface with the application of pressure, creating the visible effect of the streak.

#### Verifications—To Check:

- Hygroscopic materials such as PA, PBT, ABS, PC, PMMA, TPU, and others need a thorough pre-processing dehumidification. Check the polymer manufacturer's recommendations.
- When material is ejected, the purge bubbles may appear and release steam if the material is not sufficiently dehumidified (inconsistency of purging).
- The flow front has crater-like structures.

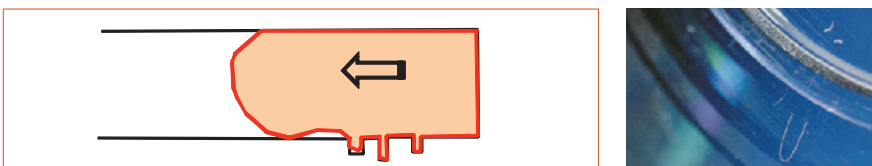
#### 25.1.2.3 Streaks Caused by Trapped Air



**Figure 25.5** Examples of streaks caused by trapped air; source: Ascamm

They appear as matte, silver, or white streaks near the last filling zone. They also appear in areas with ribs, thickness variations, letters, reliefs, etc. The air concentrated in the ribs and grooves can be surpassed by the flow front and be trapped in the melt.

The air unable to escape during filling goes to the surface and becomes compressed in the direction of flow during the hold pressure stage.





**Verifications—To Check:**

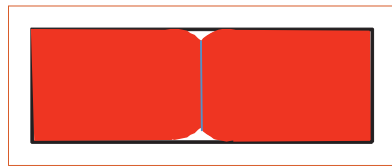
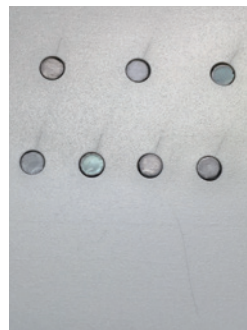
- Make sure that the suction is not the cause of the problem.
- Perform tests decreasing the injection speed to minimize the problem.
- See if ejection purge shows bubbles or explosions and if the flow front has craters.
- Verify the back pressure. If the back pressure is low, the air is not completely removed from the pellets during dosing.
- Verify possible wear in the screw barrel of the plasticizing unit.

**25.1.3 Weld Lines**

When several flow fronts face each other, the flow front edges that are rounded come in contact and are crushed against each other. If temperature and pressure are not high enough, the corners in contact with the cavity will not bind on the entire surface and microcracks appear. Fluids do not mix homogeneously. At this time it is very important that the aeration or venting of the mold has been effective.



**Figure 25.6** Weld lines



**Figure 25.7** Weld lines between two flow fronts can cause air entrapments

**Verifications—To Check:**

The flow fronts must coincide quickly and with a higher temperature to reduce the incidence of the defect. To achieve this, the following conditions could be tested and checked:

- Material with higher melt flow
- Increased mold temperature
- Increased melt temperature
- Increased injection speed
- Proper venting in critical areas
- Increased hold pressure
- Gates dimensions
- Gates location

Sometimes, we can adapt overflow areas in the welding lines position to promote that the weld line be placed out of the critical zone of the part. However, we must re-work and cut this area later.

### 25.1.4 Grooves, Vibrations, and Corona Effects

Very fine grooves formed by concentric rings, like those of a vinyl record, can be seen on the surface of the part. Their appearance is due to the formation of a solid layer behind the flow front, which is cooled very rapidly. The cooling of the peripheral layer also causes cooling of part of the flow front. When this happens, a new layer from the melt flow passes through the cold flow front, creating a new groove or line.



#### Verifications—To Check:

These actions help to increase the speed of advance of the flow:

- Increase the injection speed
- Increase the maximum injection pressure (no limited process)
- Increase the melt temperature
- Avoid small gates and channels
- Use materials with less viscosity (more fluid)

### 25.1.5 Gloss

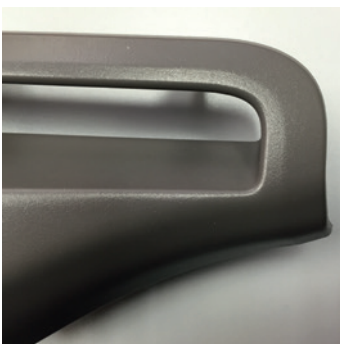


Figure 25.8 Gloss

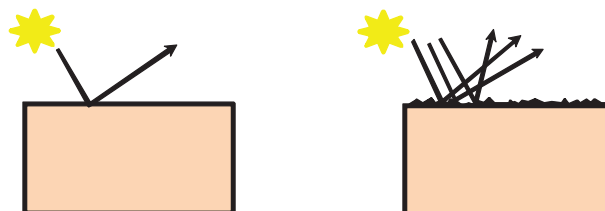


Figure 25.9 Left: high gloss, light reflection, narrow intensity distribution; right: low gloss, light reflection, broad intensity distribution

The brightness of a part is due to the refraction of light on its surface. Gloss differences are due to the different behavior of this surface, caused by various reasons (differences in mold surface, shrinkage differences, cooling differences, different mold temperature, inner vacuoles, orientation of pigments, fillers, etc.).

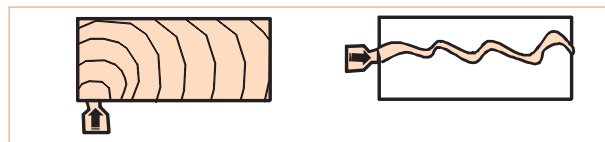
**Verifications—To Check:**

- Check the mold temperature (a high temperature causes parts with higher gloss)
- Check the melt temperature (a high temperature causes parts with higher gloss)
- Injection speed: a high injection speed usually increases the part’s surface gloss
- Cavity mold surface texturing
- Design of ejection system
- Radiate sharp corners
- Design with uniform thickness
- Provide operational venting channels
- Take into account the different temperatures in molds, runners, ejectors, etc.; these thermal gradients generate differences in surface gloss

**25.1.6 Jetting**



Jetting is a free melted material jet forcing the melt to zigzag within the cavity. When the melt touches the walls of the mold, it is cooled and cannot melt homogeneously with the rest of material that goes into the cavity.



**Figure 25.10** Correct and incorrect gate position; it can cause jetting in the molded part

**Verifications—To Check:**

- Reduce first injection speed to pass through the gate
- Increase melted mass temperature

**Advice:**

- Use lubricant grease or oils that are compatible with the polymer used
- Manufacture molded parts without stress. With this purpose:
  - Use the adequate melt temperature as recommended by the manufacturer
  - Minimize residence time of the material in the injection unit
  - Dry the material properly

### 26.2.2 Material Selection

If the stresses exceed the strength of ABS, it shall be broken without remedy. If it is possible to know the stresses applied, we can find a material that brings us a safety margin during its use.

In summary	
Problem	Broken parts during use Material: ABS
Causes	Stress cracking No radii Polymer degradation
Advice	Replace chemicals Apply radii Change melt and dry temperatures

### 26.3 Broken Gears



The absence of radii, a careless dehumidifying, and the low crystallinity of the material obtained in injected parts causes brittle fractures under stress during use.

I received several parts with visible breaks. I started watching the pieces for possible problems. They were mechanical parts used in gears, with a central housing for a square shaft. I applied a flame to try to identify the type of material and I got a strong scent: it smelled similar to a “burning horn”. When the piece burned, it formed dripping threads. It was made of polyamide (PA).

I also noted bursts and microbubbles in the surface of most parts received. Some had pores or vacuoles in the section break. I also saw the remains of a direct gate. All pieces had a very pronounced weld line in front of the gate.

**Possible Causes of Brittleness**

The samples indicate that the dehumidifying was not enough. There are traces of humidity everywhere.

The central core, squared, is not radiated on the front side, where it meets the bottom wall of the piece. This generates shear and accumulation of stresses. I

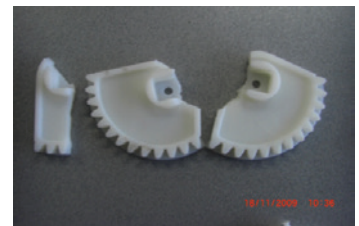
passed the pen on the radii and could clearly see a double line, indicating the absence of radius.

I observed two types of gate: a submarine and other direct by piece. If both work separately and individually, they are not sufficient to fill and package the part.

#### Advice:

- Dry the raw material (in this case PA) at 80 °C for 12 hours.
- Increase the mold temperature for maximum crystallinity of the polymer (80 °C would be suitable). This would provide more and better mechanical properties.
- Humidify or condition the parts and prepare them before including them in the assembly step. PA parts have to be conditioned to reach their equilibrium of humidity absorption, to achieve the properties of use.
- Radiate cores in the central square of the base, where it meets the wall of the part.
- Increase direct gate in order to compensate the shrinkage that promotes the internal vacuoles.

In summary	
Problem	Broken parts during use Material: PA
Causes	Mold temperature No radii Irregular drying Gate with incorrect dimensions
Advice	Increase mold temperature Apply radii Correct and proper material drying Increase the gate dimension



## 26.4 Unfilled PC Cover

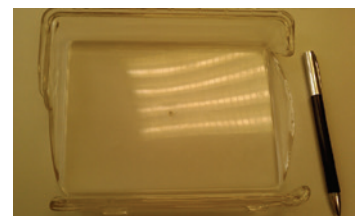


Improper thickness of the wall connected to the gate prevents the proper filling of the transparent PC sheet.

In this case, the problem was in a transparent cover made of polycarbonate (PC). The filling of the cavity was hard and flow lines and corona effect (see Chapter 15) were seen in areas far away from the gate.

After cutting the piece, I noticed that the wall where the gate is located (this is in the center of the part) was too thin (1 mm) in relation to the perimeter side walls (4 mm), rather thick.

The “thick to thin” rule is not observed in this case. Neither has been included a semi-spherical facilitator flow in front of the gate. This simple mechanization



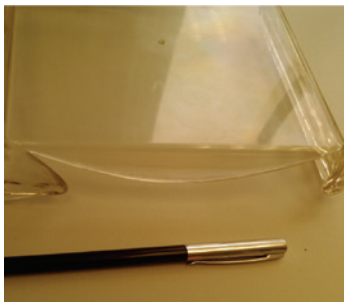
facilitates filling, especially at first, and minimizes friction and shear near the gate.

The gate is too small for the volume and section of the part. If we double the gate section, we quadruple the volume that can pass through it.

It is recommended that the wall connected to the gate should be the thinner wall of the part. Flow restriction prevents the filling and holding pressure of the cavity in the thicker areas.

**Advice:**


- Review design to increase the thickness of the wall connected to the gate
- Warm the mold (PC can be worked at 90–100 °C)
- Have a facilitator flow in front of the gate
- Increase the gate section for easy filling and packing of the cavity
- Use a more fluid PC



In summary	
Problem	Incomplete parts Material: polycarbonate
Causes	Wall design with incorrect gate No flow facilitator in front of gate Gate with inadequate dimensions
Advice	Increase mold temperature Mechanize facilitator for easy filling Increase the gate section Use more fluid material

## 26.5 Dimensional Instability in Parts



 Cavity filling imbalances cause unacceptable dimensions differences in the parts.

In this case, the difficulties encountered to manufacture consistent dimensions in precision parts make it impossible to carry out the work.

During fabrication of a colored transparent polystyrene (PS) ring, the degree of dispersion of the dimension obtained exceeds the specified tolerance for this product. The tolerances for these products are very low and cannot stabilize the dimensions variation range.

After a meeting with the customer, I visited the injection plant to observe the full injection process. The three plates mold has eight cavities. Such a high number of cavities is not recommended when one wants to make very high precision parts.

I decided to measure the parts and analyze the cavity number groups. I saw a significant spread between the parts obtained from different cavities number.

At this point I wondered:

- Is the switching point correct?
- On many occasions this point is not properly programmed, causing:
  1. Overcompaction
  2. Partial filling of the part during the hold pressure stage, without speed control
- Is the injection pressure limit being reached?

Often, the filling is limited by the injection pressure limit and we have no control of the speed of filling the cavity.

- Does the flow front advance uniformly?

Normally, injection speed profile curves are set flat or with a constant injection volume during all the filling stroke. This causes the flow to accelerate or decelerate according to the sections of passage of the material, runners, etc. We do not control the flow front speed.

- Is the hold pressure time right?

Normally, this time is set depending on the weight (there are two limits) or depending on the part (dimensions, flashes, grips, etc.), or when the part fails to gain weight. We should not make perfect runners by increasing hold pressure time, cycle, or energy expenditure.

- Do we want to switch to hold pressure stage by hydraulic pressure?

Normally, this system is not too used although it is the most reliable (outside the cavity pressure switching) and is available in almost all current standard machines. We must make better use of available technology in factories.

**We make a start from zero, following these steps:**

### **Injection Pressure Limit**

Set the pressure value above the real pressure needed to ensure that we do not limit the injection process. There is nothing worse than a pressure-limited process.

### **Holding Pressure**

Set the hold pressure time and hold pressure to zero.

### **Switching Stroke**

Set the switching point close to the dosage point in order to inject a little injection volume in the cavity. We want to fill only a small amount of the part.

**With these premises, we can start the progressive filling of the cavities.**

During filling, we modify the switching point position to inject a greater quantity of material in each cycle. Suddenly, we find that certain cavities are completely filled while others are not. The eight cavities have not been filled in a balanced way. The probable cause is the small differences in gates and/or runners channels, in addition to the “spiral” effect. Here we identify a cause of the spread of dimensions between cavities.

We cannot obtain narrow dimensional tolerances in an unbalanced mold during filling.

After obtaining the correct switching point position, we proceed to pressurize and pack the cavities. We use the gate seal analysis. First we select a hold pressure time excessively overrun, which ensures that the gate will be closed or sealed and a low hold pressure level.

We increase the pressure values until the pieces are aesthetically and dimensionally correct. At this point we have an excessive holding pressure time, which ensures the gate seal. Then we weigh the injected parts without runner and we gradually reduce the holding pressure time, controlling the weight of each shot.

There will come a moment when the weight will decline. This indicates that the gate was not sealed. So we increase in the previous the step holding pressure time, 1 second or so, and ensure the sealed gate with the shortest hold pressure time possible and, therefore, the optimum time.

Finally, we decrease the pressure injection limit to a value slightly above the necessary real filling pressure. In this way we ensure that it does not interfere with normal filling cavities, and it becomes a security element to any clogged or closed cavity.

With these steps, the dimensions of injected parts are dimensionally repetitive and consistent and will be dimensionally stable although the cavities filled first are bigger. To eliminate this last problem we have to ensure that the dimensions of channels and gates are identical.



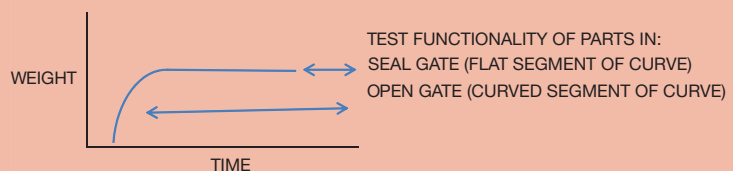
### Hold pressure

Key points:

1. Do we work with a sealed gate or with an open gate?
2. How much time will be set in hold pressure stage?
3. How much hold pressure will be set?

Points 1 and 2 determine if we work with sealed or open gates.

1. Place a hold pressure time much longer than necessary to seal the entrance
2. Start with a low hold pressure and gradually increase until the piece is OK. This pressure is to study the sealing time of the gate. It is not the pressure with which we will work
3. Weigh the part
4. Gradually reduce hold pressure time and weigh the part until we have 0.5 seconds holding pressure
5. Reflect times and weights on a chart



Sealed gate processes are better and more stable.



**Advice:**

- Match and balance filling between cavities; adjust gates and channels if necessary
- Change the injection process for an optimum hold pressure time with sealed gate
- Adjust any cavity if it is outside the tolerance range

In summary	
Problem	Process with little robust dimensions Dimensional instability
Causes	Cavity unbalanced Unoptimized hold pressure
Advice	Balance filling between cavities Set post-pressure correctly Work with sealed gate

## 26.6 Insufficient Filling



A change in the polymer used may hinder the filling of the cavity.

In this case, the part was made with a blend of PC-ABS. This blend is a material of high/medium viscosity. The flow path respect to the average thickness of the part was quite unfavorable. The average thickness of the part was 2.5 mm.

Looking at the gates, two submarine gates of small dimensions were connected to the rear walls. These walls were too thin.

In this case there had been a change of material. Previously, the material filled perfectly with this mold. The filling problems began when it was replaced by the new blend.

Given the large difference in viscosity between the two materials, it was necessary to review and modify certain aspects of the mold to properly fill the cavity.

Although the value of the MFI in each case is important, it can lead to certain errors. For example, if we look at a PP and a PC with a melt index of 4 g/10 m, this does not mean that we can fill the same cavity with both materials. In the case of PP, its viscosity may decline by a factor of 100 because of the shear rate, and, in the case of PC, the viscosity can be reduced by only a factor of 5.

**Advice:**

- Modify distribution channel, increasing the section
- Increase the section of the runner and submarine gate
- Increase the gate section
- Increase rear walls section connected to the gate



# Index

## Symbols

30/30 melt temperature measuring method 323

## A

absorption of water 37  
ABS part 359  
accelerated weathering test 106  
acronyms 41  
acrylonitrile butadiene styrene (ABS) 52  
acrylonitrile styrene acrylic rubber (ASA) 54  
additives 6, 74  
adhesion 344  
advanced technician 265  
aesthetic aspect 363  
aesthetic defects 284, 362  
aesthetic limitations checklist 130  
aliphatic compounds 69  
alkalis 67  
allowed humidity 385  
amines 69  
amorphous 8  
antiblocking additive 81  
antifriction lubricants 84  
antioxidant additive 74, 76  
antistatic compounds 77  
application environment, requirements checklist 129  
atactic 12  
atmospheric plasma treatment 260  
axially symmetrical parts 320

## B

back pressure 30, 186, 198, 207, 332, 337, 368, 375  
back pressure recommendations 209  
bactericide additive 87  
bacteriostatic additive 87  
Bakelite 23

balanced distribution channel 220  
balanced filling system 370  
ball pressure hardness test 90  
ball valve 170  
barrels 303  
barrier screws 303  
beryllium copper 218  
bifunctional 6  
bimetallic effect 360  
bimetallic hard treatment 168  
birefringence in transparent polymers 108  
black spots 336  
blend ABS-PC 53  
blisters 343  
block copolymer 374  
blushes near the gate 337  
bonding of materials 157  
breaks 357  
break stress 118  
brittle fractures 350  
brownish discoloration 330  
bubbles 337, 343, 376  
bubbles and peaks 343  
bulk density 115  
burns 330  
burn test 35  
butadiene particles size 343

## C

calculation  
– estimated clamping force 165  
– intensification ratio 289  
– portability of process 289  
– process analysis and optimization 289  
– residence time in the injection unit 289  
– scientific injection molding tools 289  
– shear in rectangular gates 289  
– shear in round gates 289  
– turbulent flow (NR) 289  
carbon 4

cavities balancing study 283, 284, 289  
cavity filling 31, 181  
cavity filling imbalances 352  
cavity mold surface texturing 334  
cavity pressure 206  
central flow distribution channels 238  
Charpy test 92  
check valve non-return tip 170  
chemical resistances 66  
clamping force 162, 194  
clamping unit 161  
clamping unit systems 162  
CLTE test 97  
coefficient of linear thermal expansion (CLTE) 120  
cold layer 182  
cold runner 252  
cold slug 229, 310  
collodion 22  
comparative tracking index CTI 136  
comparative tracking index test 112  
compatibility agents 82  
compensation of the volumetric shrinkage 347  
compression ratio 167, 303  
compression set test 94  
compression zone 167  
concentric circular, dark area around the gate 356  
contact angle 259  
conversion systems 282  
cooling 30, 254, 376  
cooling part 29  
cooling speed 190  
cooling stage 27  
cooling system in cores 226  
cooling time 195, 279  
cool skin 280  
copolymer 12  
copolymer POM 50  
corona 341  
corona effect 333, 351  
corona treatment 260

correct cavity balance 284  
 cost requirements checklist 130  
 covalent bonds 4  
 cracking 337  
 cracking of polymers 66  
 cracks 329, 339  
 crawling 340  
 craze 329, 349  
 crazing of polymers 66  
 creep 19, 248  
 creep modulus 21  
 cross cut test 341  
 cross-links 11  
 crystallization of polymers 33  
 CTI test 102  
 cushion 192  
 cycle time 190

**D**

defects 343  
 defects due to the gates 251  
 defects in chrome plating on plastic parts 342  
 deformation at constant load 241  
 degradation of polycarbonate 336  
 degree of polymerization 3  
 delamination 337  
 delta P 266, 274  
 delta P study 289  
 demolding taper 376  
 density 114  
 deposits in the mold, cause 325  
 deposits, recommendations to prevent 326  
 depth of the gate 337  
 deviations 263  
 deviations between cavities 284  
 dew point 317  
 diagram molding 277  
 diagram of molding area 278  
 dielectric constant test 102  
 dielectric strength 137  
 dielectric strength test 102  
 diesel effect 198, 347  
 differential shrinkage 359, 361  
 dimensional instability in parts 352  
 direct gate 234  
 dispersion 85

dissipation factor test 102  
 distribution channel 372  
 dosage 192  
 dosage and metering zone 168  
 dosage calculation 289  
 dosage stage 26  
 dosage stroke 195, 207  
 double bonds 4  
 draft angles 230, 357  
 drooling material 197  
 drop injection pressure study 289  
 dryers 379  
 dryers and dehumidifiers 305  
 drying of material 345  
 drying system 379  
 dull spots 363  
 dyes and pigments 84

**E**

ejection stress 357  
 ejectors 375  
 ejector stroke 201  
 ejector venting design 256  
 elastomers 11, 59  
 elastomer thermoplastic vulcanized (ETPV) 60  
 empirical method 264  
 environmental stress cracking (ESC) 70, 349  
 equivalences between different steels 219  
 esters 67  
 ethers 66  
 ethylene vinyl acetate (EVA) 50  
 ethylene vinyl alcohol (EVOH) 50  
 excessive material drying 327

**F**

failure analysis 303  
 fan edge 231  
 fiber orientation 371  
 fibers 82  
 filling in a balanced way 353  
 filling pressure 30  
 filling pressure at switch point 266  
 filling speed rate 182  
 filling system 317

filling system review and optimization 347  
 filling time 202, 265, 274  
 flame retardants 77  
 flaming 341  
 flashes 272, 277, 303, 315, 363  
 flash gate 234  
 flat nozzle 172  
 flexural modulus 89  
 flexural test ISO 178 89  
 flow front 353  
 flow restriction 352, 358  
 foaming agents 81  
 forced air heaters 345  
 functional group 6  
 functionality 6

**G**

gas bubbles 331  
 gate 318, 368, 371  
 gate depth 250, 348  
 gate, frozen 279  
 gate length 348  
 gate position 225, 319  
 gates and runners design 252  
 gates design 224  
 gate seal analysis 267, 354  
 gate seal study 278, 287, 289  
 gate seal study curve 279  
 gate section 335, 368  
 gates, most common 224  
 gates recommendations 209  
 gate too small 352  
 gate types 231  
 gate width 348  
 gate width and length 250  
 generic recommendations 209  
 glass microspheres 82  
 glass transition temperature 15, 94  
 gloss 333, 363  
 graining and peaks 363  
 grinders 306  
 grooves 333  
 gutta-percha 22  
 GWFT test 101  
 GWIT test 101

- H**
- halogenated compounds 69
  - halogen-free flame retardants 79
  - halogens 79
  - HALS 75, 76
  - haze 155
  - HDT 138
  - HDT, DTUL 95
  - heat conductivity 125
  - heat deflection temperature 122
  - hesitation effect 361
  - heterodisperse 7
  - high ampere arc ignition test 111
  - high density polyethylene 46
  - high gloss 333
  - high-performance polymers 149
  - high residence time 330
  - high shear 344
  - high voltage arc resistance to ignition test 111
  - high voltage arc tracking rate test 111
  - hinges 320
  - holding injection pressure phase 276
  - hold pressure 27, 30, 188, 199, 202, 207, 209, 375
  - hold pressure stage 27, 203, 321
  - hold pressure switching 188
  - hold pressure time 29, 189, 353
  - hold pressure time with sealed gate 355
  - holes and craters 338
  - homodisperse 7
  - homogeneous melt 186
  - homogeneous thicknesses 243
  - homopolymer 11
  - homopolymer POM 50
  - horizontal HB test 98
  - hot-air ovens 345
  - hot ball pressure test 96
  - hot runner 222, 307
  - hot runner nozzle 254
  - hot wire ignition HWI 139
  - hot wire ignition test 110
  - hydraulic piston clamping system 163
  - hydrocarbons 5
  - hydrolysis 37, 38
  - hydrolysis stabilizers 81
  - hydrolyzed parts 37
  - hydrophilic polymers 38
  - hydrophobic polymers 38
  - hygroscopic materials 331
- I**
- identification of plastics 36
  - impact modifiers 82
  - impact resistance 119, 246
  - incandescent glow wire test 100
  - increasing surface tension 260
  - injection and cavity pressures 205
  - injection graphs 365
  - injection molding machine 161
  - injection peak pressure 275
  - injection pressure 187, 194, 209
  - injection pressure at switching point 202
  - injection pressure evolution 203
  - injection pressure limit 274, 276, 353
  - injection pressure losses 280
  - injection process 263
  - injection speed 178, 198, 207
  - injection speed linearization study 271
  - injection speed machine performance 269
  - injection speed profile 335, 353
  - injection speed units conversion 289
  - injection stage 26
  - injection unit 161
  - in-mold rheology 288, 289
  - inner ring gate 235
  - input and output water lines 359
  - inputs and outputs 282
  - insufficient filling 355
  - intensification ratio 266
  - internal and external undercuts 246
  - internal micropores 365
  - internal stresses 343
  - internal voids 347
  - intumescence 78
  - ionomer 63
  - ISO 5271-2 88
- J**
- jetting 320, 334
- K**
- ketones 68
  - key parameters 204
- L**
- lack of adhesion 341
  - lack of crystallinity 324
  - lack of ventilation 364
  - lamellae 33
  - land channel 364
  - $L/D$  ratio 167
  - length or land of the gate 319
  - light stabilizers 75
  - limited oxygen index (LOI) 142
  - linear 11
  - linear low density polyethylene (LLDPE) 47
  - liquid crystal polymer (LCP) 59
  - LLDPE 47
  - LOI test 99
  - low density polyethylene 46
  - lubricants 75
- M**
- machine injection speed performance study 289
  - machine nozzle 369
  - machine portability 282, 289
  - masterbatch 85
  - material degradation 372
  - materials drying 316
  - material selection 134
  - material viscosity 208
  - matte surface 363
  - maximum available pressure 281
  - maximum peripheral screw speed 194

- maximum recommended moisture 346  
maximum shear friction recommended 285  
Maxwell-Voigt model 19  
mechanical toggle clamping system 163  
medium or high impact PS (HIPS) 52  
melt flow index 116  
melt flow rate (MFR) test 104  
melting temperature 16, 94  
melt temperature 184, 206, 322  
melt temperature measurement 322  
melt temperature recommendations 209  
melt volume index 115  
metal or plastic inserts 320  
MFI 355  
microbubbles 350  
microcraters 357  
microstreaks 380  
mineral additives 83  
mineral fillers 83  
moisture 37  
mold care 326  
mold cooling 226  
mold deposits, types of 325  
mold design 182  
mold design guide 218  
molding processor 264  
mold surface temperature 323  
mold temperature 190, 191, 206, 383  
mold temperature recommendations 209  
mold temperatures setting 196  
molecular orientation 335  
molecular weight 7, 371  
monomers 3  
multiple machine drying system 289
- N**
- Newtonian area 272  
nitrided screw 169  
notches, influence 245  
nozzle 171, 304  
nozzle diameter 252, 366  
nucleating agents 81
- O**
- open nozzle 172  
optical brighteners 86  
optimum injection speed range 269  
optimum time for holding pressure 279  
orientation 344  
oriented material layers 337  
outer ring gate 235  
overdrying 327  
overlarged jump gate 236
- P**
- painting 339  
parameters deviations 192  
part dimensions 199  
parting lines 303  
part molded with stress 339  
part requirements checklist 129  
part temperature 207  
part weight control 279  
PC-ABS 355  
peaks 343  
percentages of pressure loss 280  
peripheral screw speed units conversion 289  
peripheral speeds 387  
peripheric screw speed recommendations 209  
pin gate 236  
pin point gate 232  
plasma 341  
plasticization 37, 38  
plasticizers 76  
plasticizing capacity 167  
plastics 3  
plastic parts design 239  
platens 303  
plating process 343  
PMMA 361  
polar moment of inertia 240  
polyacetals 23  
polyamides (PA) 54  
polybutylene terephthalate (PBT) 56  
polycarbonate 58, 356, 367  
polydispersity 7  
polyester 56, 316  
polyester polyol 62  
polyether polyol 62  
polyethersulfone (PESU) 64  
polyethylene 23  
polyethylene terephthalate (PET) 56  
polymerization 3  
polymers 3  
polymethylmethacrylate (PMMA) 58  
polyol 374  
polyolefins 46  
polyoxymethylene (POM) 50  
polyphenylene oxide (PPO) 57  
polyphenylene sulfide (PPS) 63  
polyphenyl sulfone (PPSU) 64  
polypropylene (PP) 49  
polystyrenes (PS) 51  
polysulfone (PSU) 65  
polyurethane (TPU) 61  
POM 357  
POM foaming test 257  
POM homopolymer 31, 257  
portability 282  
portability spreadsheet 283  
post-shrinkage 324  
PP copolymers 49  
precious runners 279  
preliminary investigation of failures 309  
pressure drops 280  
pressure evolution 187  
pressure-limited process 274, 280, 365  
pressure multiplier 176  
pressurized water 325  
previous calculations 194  
process optimization 310  
process outputs 265, 282  
process start-up 193  
process validation 282  
process window 267, 276, 277  
process window study 289  
progressive filling 280  
progressive mold filling 202  
progressive mold filling setting 201  
proper crystallization 324  
properly adjusting the mold temperature 324  
properly dehumidifying 317

purging or cleaning 255  
PVT graphs 25

## R

radiation 107  
radii 310, 349  
ratio dosage/screw 175  
reaction to fire 101  
refraction of light 334  
refractive index 108  
refrigeration system 304  
regrind, amount 330  
relative temperature index, RTI 125  
relative temperature index test 112  
relative viscosity method 267  
relaxation 20, 248  
residence time 335, 383  
residence time of material 175, 195  
residence time recommendations 209  
residual stress 108, 339  
resin handling 307  
reverse taper nozzle 172  
rheology 13  
rheometer 115  
ribs and reinforcements designs 239  
ribs design 240  
rigidity 248  
RTI test 96  
runners 318, 374  
runners and gates systems 250  
runners and sprue 370  
runners design 220, 221  
runners ejectors 364

## S

saving material solutions 241  
scientific method 264  
scientific molding 263  
scratch resistance test 93  
screw 167, 303  
screw holes 249  
screw mechanism 169  
screw non-return valve hermeticity study 289  
screw peripheral speed 185

sector regulations checklist 130  
semi-crystalline 9  
semi-spherical facilitator 351  
servoelectric clamping 164  
sharp corners 244, 334, 337, 357  
sharp edges 349  
shear 337  
shear calculation 286  
shear rate 14, 285  
shear stress at the gates 284  
shear stresses 280  
Shore A 91  
Shore D 91  
short hold pressure times 321  
short parts 277  
shrinkage 209, 230, 279, 384  
silica 305  
silver marks 337, 369  
silver streaks 330, 331  
sinkings 340  
sink marks 277, 320, 328  
slips additive 81  
slots and undercuts 246  
small gates 318  
small holes 338  
snap-fit 247  
solvent 339  
specific injection pressure 177  
specific units 282  
specific volume 25, 26  
speed profile 180  
spherical nozzle 172  
spherulites 34  
spiral effect 253, 284, 353  
splay 337, 369  
spots 343  
spots and markings near the gate 335  
sprue diameter 252  
sprue diameter, small 250, 319  
stabilizers 74  
start-up and fine-tuning of injection machines 201  
steel selection 219  
steps for analysis 311  
strain 88  
strain at break 118  
streaks 315, 330, 357, 367

streaks caused by moisture 330  
streaks caused by trapped air 331  
stress 88  
stress concentrators 245, 346  
stress cracking 110, 338, 349  
styrene acrylonitrile (SAN) 53  
styrene butadiene copolymer (SBC) 62  
submarine or tunnel gate 232  
subrunner 250  
substrate 339  
suction 198, 368  
surface orientation 183  
surface resistivity 124, 135  
surface resistivity test 103  
surface scratching 338  
surface tension 258, 341  
switching point 202, 278, 353  
switching point to holding pressure 344  
switching pressure 200  
switching to hold pressure stage 199  
syndiotactic 12  
systematic progressive 272

## T

Taber test 90  
tab gate 233  
tangential screw speed 185  
tangential speed 186  
taper nozzle 172  
target factor values checklist 131  
technical specifications checklist 130  
Teflon 23  
temperature 196  
tensile modulus 118  
tensile stresses 241  
tensile test 88, 118  
theoretical clamping force estimation 289  
thermal conductivity 123  
thermodynamics 25  
thermographic analysis 359  
thermoplastic copolymer elastomer ether ester (TPC ET) 60  
thermoplastic elastomer (TPE-V) 59

thermoplastics 8  
thermoregulators 307  
thermostable 10  
thickness, changes 243  
thickness design 242  
thickness of ribs 239  
thickness problems 242  
thick to thin 320  
thick to thin rule 351  
time-dependent process 279  
time of arc resistance test 111  
titanium nitride 326  
toggle kinematics 197  
torsion resistance 240  
TPC-ET 345  
TPU 373  
transparent polymers 156  
trapped air 338, 377  
traverse optimal temperature test 289  
trials injection molding parameters template 314  
troubleshooter questions 311  
tubular frames 249  
tubular parts 320  
turbulent flow 304, 359  
typical problems in plastics injection 315

## U

UL94 97  
UL temperature *See* relative temperature index RTI  
unbalanced runners 220, 252, 372  
uncompensated shrinkage 377  
unfilled part 351  
universal process data sheet 289  
UV protection 76

## V

vacuoles 318, 329, 346  
vacuum problems 375  
vaporization 38  
venting 227, 255  
venting channels 386  
venting depth for amorphous plastics 228  
venting depth for semi-crystalline plastics 227  
venting depth recommendation 256  
venting for runners 228  
venting in ejectors 229  
venting length 256  
venting recommendations 209  
Vicat softening temperature 121  
Vicat test 95

viscosity 13, 269  
viscosity curve 273  
volume resistivity test 104  
volume shrinkage 321  
vulcanization 22

## W

warpage 338  
warping 320, 360  
water influences 37  
water in polyamides 37  
weathering test 105  
weight at switch point 266  
weld lines 183, 190, 332, 350, 356  
white streaks 331

## Y

yield point 118  
yield stress 117